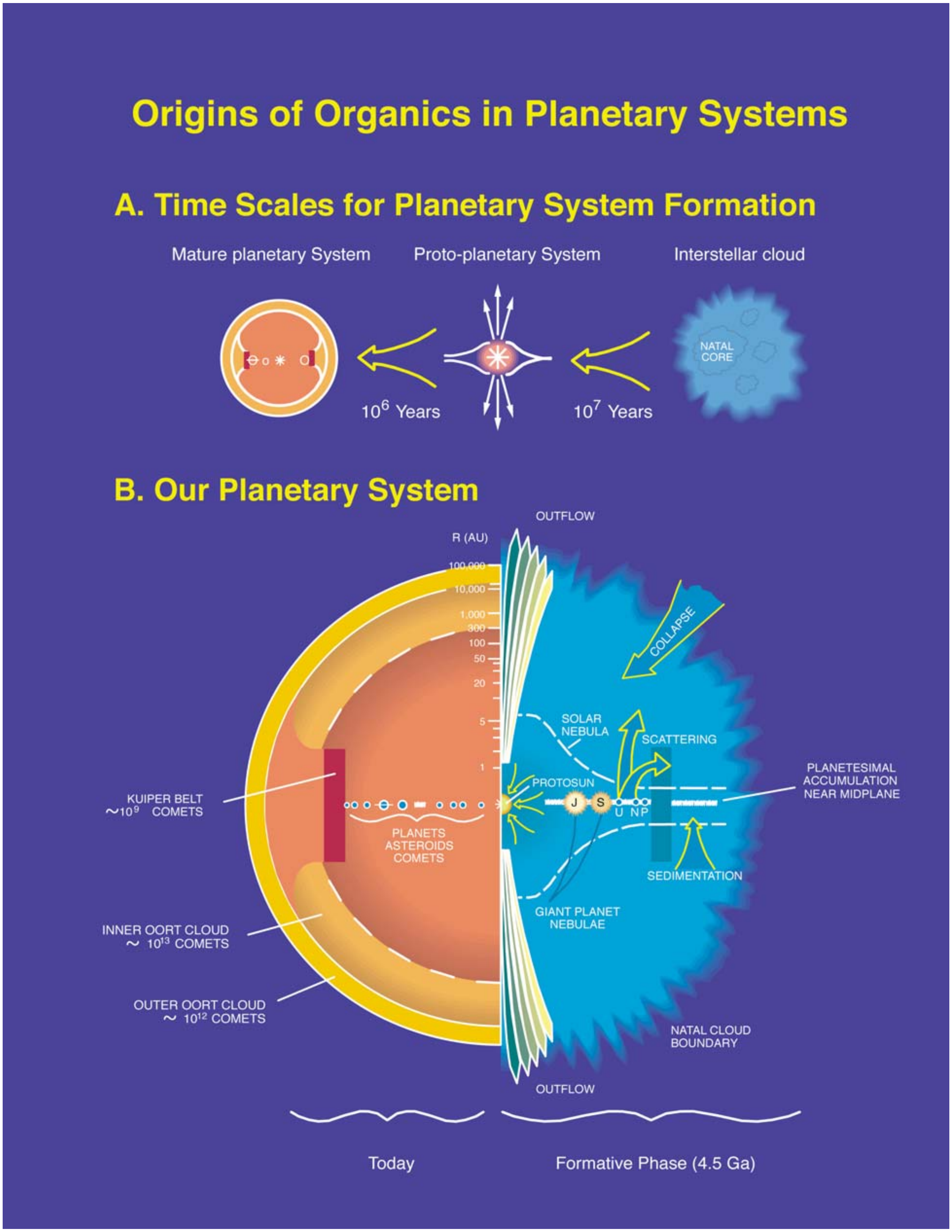

Frontispiece

Executive Summary

Planetary Systems form by collapse of dense interstellar cloud cores (Frontispiece). Some stages in this evolution can be directly observed when stellar nurseries are imaged (Figure ES.1), while other stages remain cloaked behind an impenetrable veil of dust and gas. Yet to understand the origin of life on Earth, we must first develop a comprehensive understanding of the formation of our own planetary system.

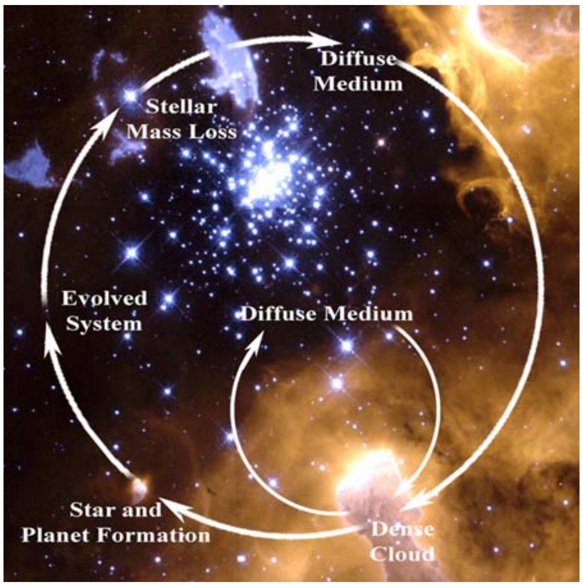

Figure ES.1 HST image of NGC 3603 showing the life cycle of material (including carbon) in a star-forming region. A cycle of stellar birth and death leads to the synthesis and evolution of organic compounds. Carbonaceous material ejected from dying stars enters the diffuse medium and then is cycled into dense clouds. The collapse of a dense cloud forms an evolved stellar system (see the Frontispiece for more detail) where these organic compounds can be delivered intact to planetary surfaces and mixed with those produced endogenously. As the lifetime of the evolved system comes to a close, stellar mass loss recycles material to begin the process anew.

Dense cloud cores are very cold (10-50 K), and their dust grains are coated with ices comprised of water and organic compounds. Many of these organics have potential relevance to the origin or early evolution of life, if delivered to planets.

The survival of these organics through the violent birth-phase of a star is less certain. Properties of the young star (its mass, spectral energy distribution, whether it formed in isolation or as a multiple star, etc.) play a key role in controlling the evolution of organic material in the proto-planetary disk. The location within the disk is important since the nature and effectiveness of such processing depends strongly on distance from the young star, on distance above the nebular mid-plane, and on time. The ultimate delivery of these primitive organics to young planets and their moons also evolves with time, as the bodies grow in size and as the nebula clears.

We propose to investigate the origin and evolution of organic compounds in planetary systems, and their delivery to young planets.

The proposed research addresses the heart of Goal 3 of the Astrobiology Roadmap:

Understand how life emerges from cosmic and planetary precursors.

The central question is this:

Did delivery of exogenous organics and water enable the emergence and evolution of life?

The investigation is divided into four Themes:

Theme 1: *Establish the taxonomy of icy planetesimals and their potential for delivering pre-biotic organics and water to the young Earth and other planets.*

Theme 2: *Investigate processes affecting the origin and evolution of organics in planetary systems*

Theme 3: *Conduct laboratory simulations of processes that likely affected the chemistry of material in natal interstellar cloud cores and in proto-planetary disks.*

Theme 4: *Develop advanced methods for the in-situ analysis of complex organics in small bodies in the Solar System.*

We seek to better understand the organic compounds generated and destroyed in the interstellar and proto-planetary environments, through observational, theoretical, and laboratory work. We will examine the potential for and limitations to delivery of exogenous pre-biotic organics to planets, examining factors that enhance or restrict this potential.

We will, for the first time, investigate the effect of astrophysical X-rays on the evolution of exogenous organics in proto-stellar disks. We will follow these factors over time, from the natal cloud core through the end of the late heavy bombardment (~ 4.1 Ga). We will evaluate the possible role of exogenous organic material in terrestrial biogenesis.

The proposed research will significantly improve our understanding of the nature of organics in other planetary systems, the processes affecting them, and the potential for delivering pre-biotic organic compounds to planets.

The Management plan: An Integrated Research Approach

The proposed research is interdisciplinary and it involves researchers at multiple institutions. This is both an intellectual asset and an organizational challenge. The effectiveness of a Team is demonstrated when its total output exceeds the sum of its individual parts. We have developed a management strategy that we believe will enable this objective.

- *Internal collaboration will be enhanced by bridging post-doctoral associates and students across projects within a Theme.*
- *Theme-Based "Expeditions" will be mounted to ensure that our students receive hands-on experience in techniques used in all Themes.*
- *Students and post-docs will be encouraged to explore other aspects of Astrobiology at luncheons every two weeks.*
- *An Executive Scientist will ensure smooth operations of the Node, and timely reporting to NAI Central and to NASA Headquarters.*
- *An Executive Committee will review the scientific progress and activities, monthly. An independent Board of Visitors will assess progress on an annual basis.*
- *An Education and Public Outreach Lead will ensure that our E/PO plan is smoothly executed.*

Education and Public Outreach.

GSFC and the Minority Institute Astrobiology Collaborative (MIAC) will implement a multi-faceted program based on Astrochemistry and focused on organics in the solar system. We will develop curriculum materials, conduct teacher professional development workshops, and bring observational cometary research into middle and high school classrooms. We will support MIAC institutions in the professional development of K-12 educators in under-served communities and build upon existing MIAC, GSFC and UMCP (Deep Impact EPO) programs and educator networks.

Lead Institution Commitment

NASA's Goddard Space Flight Center has long-established scientific expertise in all four Theme areas. The proposed research draws upon large and highly productive ongoing programs in areas of Laboratory Astrochemistry; Planetary Systems research; Interstellar, Stellar, Planetary, and Cometary spectroscopy; and Flight Instrument Development.

The Center has made an advance commitment to the Astrobiology Program by hiring Drs. Jason Dworkin and Michael DiSanti as civil servants, and providing infrastructure support to them. Goddard also plans to fill additional civil service positions in the areas of nebular and cometary chemistry.

The Center has recently devoted an NAS-NRC Resident Research Associateship to Astrobiology and is actively seeking a candidate to fill this position. If our Node is selected, the Executive Scientist will re-locate to Goddard. Visiting faculty, post-doctoral associates, and graduate students will be supported to augment the already significant scientific complement at the Center.

Leverage

This proposal heavily leverages the existing research programs of the individual Investigators. Our Investigators have access to advanced laboratories and observatories through their existing institutional arrangements and partnerships.

Principal Objectives

Theme 1: *Organics in Icy Planetesimals: A Key Window on the Early Solar System*

A. Comet taxonomy via specific molecules and isotopes
   1. Measure abundances of parent volatiles
   2. Measure the ratio HDO/H_2O
   3. Measure abundances of chemically related molecules

B: Perform detailed theoretical studies of the molecular chemistry of proto-stellar disks
   1. Model in-fall for specific chemical changes in the major volatile components
   2. Determine how trace cometary organics can also be formed at the accretion shock
   3. Model interstellar deuterium fractionation as ISM material incorporates into the nebula

C. Model dynamical transport of icy planetesimals in the early Solar System
   1. Model organic flux into Oort cloud, terrestrial region, and out of the Solar System
   2. Model 1 including giant planet migration
   3. Model 2 including the formation of Uranus and Neptune
   4. Simulate the growth of grains followed by settling to the mid-plane

D. Determine isotopic compositions and abundances in Lunar breccias
   1. Determine the signature(s) of highly siderophilic abundances in Lunar breccias
   2. Connect signature(s) to materials exposed to early Solar System processes
   3. Determine if the composition of the late influx changed with time
   4. Connect siderophilic impactors with those of organic-rich chondrites

Theme 2: *From Molecular Cores to Planets: Our Interstellar Heritage*

A. Study the evolution of material in molecular clouds
   1. Map chemical abundances to determine the physical conditions within a molecular cloud
   2. Search for new interstellar organic molecules

B. Determine the initial conditions for planet formation
   1. Understand the growth of grains prior to and during incorporation in the disk
   2. Observe grain growth and document opacity loss as material gets incorporated mm scale bodies
   3. Determine the relationship between cometary and interstellar chemistry

C. Connect the X-rays and UV from young stars to formation and destruction of organics
   1. Compare abundances of organics around young stars with models and lab simulations
   2. Measure the emission and ionization state of molecules near young stars
   3. Measure changes in the chemical abundances as a consequence of strong X-ray and UV flaring

D. Search for organic signatures in the IR spectra of transiting extra-solar gas-giant planets

Theme 3: *Organic Material from Laboratory Simulations of Astrophysical Environment*

A. Analyze complex organics in grain-catalyzed reactions
   1. Investigate organics in hydration and thermal metamorphism ala various meteorite types
   2. Compare results with astronomical observations, meteorites, and Earth-return samples

B. Analyze complex organics in UV, X-ray, electron, and proton processed ices
   1. Follow formation and destruction of selected organic compounds in detail
   2. Look for the formation of particularly interesting biological molecules
   3. Compare results with astronomical observations, meteorites, and Earth-return samples.

C. Analyze more complex simulations
   1. Combine materials and techniques of 3A and 3B
   2. Investigate organics in residues in various aqueous environments
   3. Follow the reactions of residues mixed with grains
   4. Follow the reactions of residues induced by additional ion or photon processing

Theme 4: *Advanced Analysis of Primitive Material*

A. Determine how to measure the history and the chemical state of organics *in situ*
   1. Evaluate a number of possible chromatographic mass spectral techniques
   2. Compare bulk pyrolysis and laser and ion beam volatilization for this evaluation (4A.1)

B. Evaluate, minimize, and manage thermal perturbations to Earth-return samples
   1. Determine how to preserve the structure and isotopic composition of relevant organics
   2. Optimize method to determine the original composition of compounds before heating

C. Utilize lab analogs to develop and calibrate instruments